

## TITRATING-DELAY MATCHING-TO-SAMPLE IN THE PIGEON

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The titrating-delay matching-to-sample (TDMTS) procedure offers researchers an additional behavioral task thought to capture some important features of remembering. In this procedure, the delay between sample offset and comparison onset adjusts as a function of the subject's performance. Specifically, correct matches increase the delay and incorrect matches decrease the delay, and steady-state titrated delays serve as the primary dependent measure. The present series of experiments investigated the effects of several procedural variables on performance in TDMTS procedures in an effort to elucidate better its features to allow for more precision in future use. Experiment 1 reports results from a parametric analysis of fixed-ratio response requirements on the sample key that indicated improved remembering in the form of higher daily titrated delay values as the requirement was increased. Experiment 2 investigated the extent to which the initial delay value in each session affected session-wide delay values. Results indicated that regardless of value of the initial delay, the subjects' performances adjusted the delay values in the direction of the known baseline delay-value levels. Experiment 3 manipulated the step size by which delay values were adjusted and the results indicated that larger step sizes increased both session-to-session variability and within-session range of titrated delay values, although the average values remained approximately the same. These results suggest that the TDMTS task serves as a promising procedure to study what many refer to as memory.

*Key words:* titrating-delay match-to-sample, conditional discrimination, remembering, memory, pigeons

The study of remembering is ubiquitous in several branches of psychology and neuroscience. One commonly employed recognition task believed to test remembering is delayed matching-to-sample (e.g., Berryman, Cumming, & Nevin, 1963; Blough, 1959; McCarthy & White, 1985; Weinstein, 1941; White, 1985). In a typical delayed matching-to-sample (DMTS) task, an experimental subject is presented with a sample stimulus. Completion of an observing response to the sample stimulus terminates sample presentation and initiates a delay (usually called the retention interval) between sample offset and the onset of comparison stimuli. A response to the comparison stimulus that matches some physical property (e.g., hue) of the previously presented sample stimulus results in the delivery of reinforcement. A response to a

comparison stimulus that does not match the sample results in a timeout. The primary dependent measure in the DMTS procedure is usually accuracy (e.g., percent correct). Accuracy values can be plotted across different delay values to determine the rate at which control by the sample stimulus is lost as a function of the retention interval—a measure often called a *forgetting function*.

The DMTS procedure has been widely used in studies with several species. Recent investigations using DMTS as a procedure to assess short-term remembering include studies with rats (e.g., Seif, Clements, & Wainwright, 2004), pigeons (e.g., Urcuioli, DeMarse, & Lionello, 1999), nonhuman primates (e.g., Sawaguchi & Yamane, 1999), humans with developmental disabilities (e.g., Williams, Johnston, & Saunders, 2006), and typically developing humans (e.g., Critchfield & Perone, 1990). In addition, the DMTS procedure has been repeatedly employed to assess pharmacological effects on short-term remembering of several drugs including amphetamine (e.g., Baron & Wenger, 2001), cocaine (e.g., Branch & Dearing, 1982), ethanol (e.g., Girard, Xing, Ward, & Wainwright, 2000), MDMA (e.g., Harper, Hunt, & Schenk, 2006), and nicotine (e.g., Elrod, Buccafusco, & Jackson, 1988).

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Although the DMTS procedure has proven useful for the study of short-term remembering in a host of experimental manipulations and investigations, two features of the procedure compromise its overall utility. First is its susceptibility to ceiling effects. Results from prior studies show that experimental subjects can often reach and maintain highly accurate performances especially under smaller delay values between sample offset and comparison onset. The upper limit on accuracy can potentially make the procedure less sensitive to the effects of programmed independent variables, particularly in procedures that seek to enhance short-term remembering. A second less-than-ideal feature of the DMTS procedure involves the arbitrary choice of delay values (i.e., conditions) across which performance accuracy is assayed. The main concern is the possibility that the selection of tested delay values could directly influence the shape of the forgetting function. For example, testing too few delay values may fail to capture certain parametric dynamics, and not testing values along a wide enough spectrum may fail to elucidate the full remembering potential of the experimental subject (see Sargisson & White, 2003, for a detailed discussion and data regarding issues of retention-interval selection).

A procedure that retains the recognition component of DMTS but avoids the two problematic features described above is a titrating-delay matching-to-sample (TDMTS) procedure. In a TDMTS procedure, the delay between sample offset and comparison onset adjusts within session as a function of the subject's performance. Specifically, some number of consecutive correct matches increases the delay on the next trial and incorrect matches decrease the delay. The primary dependent variable in the TDMTS procedure is titrated delay. Cumming and Berryman (1965) introduced this procedure in their seminal book chapter on delayed conditional discriminations. Pigeons were presented with either red or green sample key lights; every two consecutive correct matches increased the delay between sample offset and comparison onset by 1 s, and every incorrect match decreased that delay by 1 s. This contingency led to roughly 67% accuracy under steady-state performance. The virtues of the dynamic features of the TDMTS procedure were noted early on. As Cumming and Berryman (1965)

pointed out, "This titrating schedule has the obvious advantages for work with psychopharmacological agents, motivational variables, and so on, since it provides an immediate and continuous record of the bird's capability for sustaining delay." (pp. 308–309).

In a study published the same year, Scheckel (1965) reported results from rhesus monkeys performing under a similar TDMTS procedure where two consecutive correct responses in a matching task increased the delay and each incorrect response decreased the delay. Instead of making the adjustments with equal 1-s intervals, however, the delays were increased or decreased across the following values: 1, 3, 7.5, 15, 30, 50, 70, 90, and 105 s. The data appeared qualitatively similar to those of the pigeons reported by Cumming and Berryman (1965); average titrated delay values in a session, however, typically stabilized at about 45 s across the 4 monkeys, whereas pigeon values were approximately 10 s.

Subsequent research has employed the TDMTS procedure to investigate a variety of variables that may affect remembering. For example, Jarrard and Moise (1970) investigated physical restraint (chair) of stump-tail macaques to determine if the opportunity to engage in incompatible responses (e.g., grooming, movement about the chamber, etc.) affected delayed-matching performance. Three consecutive correct responses increased the delay by 2.5 s and two consecutive incorrect responses decreased the delay by 2.5 s. Results indicated no significant difference between restraint and nonrestraint conditions suggesting that intervening extraneous behavior did not interfere with retention in the TDMTS task. In another early study employing the TDMTS procedure, Ferraro, Francis, and Perkins (1971) evaluated 40 children divided into five experimental groups varying in age (51–60, 61–70, 71–80, 91–100, and 121–130 months), as a means to assess how development interacts with delayed matching performance. Their procedure required two consecutive correct responses to increase and one incorrect response to decrease the delay, but with a step size of 2 s, and results indicated that age was directly related to accuracy, with the youngest subjects (51–60 months) performing at chance after a 0-s delay and the oldest children (121–130 months) consistently adjusting delays

above 40 s. More recently, Poling, Temple, and Foster (1996) examined the differential-outcomes effect in chickens using a TDMTS procedure with results indicating that when two different reinforcer magnitudes were differentially correlated with each of two stimuli, the subjects adjusted the delay to significantly longer values.

The TDMTS procedure has also been employed to study the relation between pharmacological agents and behavior. Research on drug effects under this procedure, conducted with pigeons, nonhuman primates, and humans, have included the effects of a variety of drugs including caffeine, cocaine, *d*-amphetamine, diazepam, ethanol, linopirdine, morphine, nicotine, pentobarbital, phencyclidine, scopolamine, and thioridazine (Buccafusco, Terry, & Murdock, 2002; Buccafusco, Terry, Goren, & Blaugrun, 2003; Dayer, Baron, Light, & Wenger, 2000; Hudzik & Wenger, 1993; Nordholm, Moore, & Wenger, 1995; Wenger & Kimball, 1992; Wenger & Wright, 1990; Wenger, Hudzik, & Wright, 1993; Wenger, Hudzik, Moore, & Wright, 1996; Woodward, Watson, Blampied, & Singh, 1986; Wysocki, Fuqua, Davis, & Breuning, 1981). As one might imagine, effects on titrated delay values vary across drugs, but like pharmacological studies with DMTS procedures, systematic dose-related effects on performance are usually observed.

Although the studies discussed above show a wide range of research areas that have employed the TDMTS procedure, it should be noted that the TDMTS procedure has been used far less frequently than the DMTS procedure. As such, much less is known about the procedure and the ways in which components of this relatively complex task interact with environmental variables. The few studies, however, that have used the TDMTS procedure all suggest empirical usefulness in the collection of orderly data despite a notable variation of procedural details across experiments highlighted above. Therefore, the purpose of the present series of experiments was to elucidate better the components of this memorial task.

## EXPERIMENT 1

As discussed above, titrating delay values serve as the primary dependent measure of the

TDMTS procedure. One parameter of the TDMTS procedure that may be important in determining the titrating delay value is the number of responses required on the sample stimulus at the beginning of each trial. The assumption is that extended response requirements force the experimental subject to spend more time in the presence of the sample stimulus and this extended exposure is related to responding more effectively after a delay. Although not explicitly investigated in its own right under the TDMTS procedure, this parameter has varied considerably across studies and even within-laboratory. For example, Scheckel (1965) required only one response on the sample stimulus prior to initiation of the retention interval; Poling et al. (1996) required a fixed-ratio (FR) 5; Dayer et al. (2000) required an FR 15; Nordholm et al. (1995) required an FR 20; and Hudzik and Wenger (1993) required an FR 30.

Interestingly, this parameter has been investigated with the DMTS procedure and has been shown to produce a reliable effect—increasing the response requirement on the sample prior to initiation of the retention interval has been shown to increase accuracy (e.g., Roberts, 1972; Sacks, Kamil, & Mack, 1972; White, 1985). Because sample response requirement has been demonstrated to be an important parameter of the DMTS procedure, and moreover, due to its inconsistent previous use without explicitly stated rationale with the TDMTS procedure, Experiment 1 conducted a parametric analysis of the effects of this parameter on performance in the TDMTS procedure.

## METHOD

### *Subjects*

Four experimentally naïve White Carneau pigeons (*Columba livia*), approximately 1 yr old, obtained from Double-T Farms, Glenwood, Iowa, served as subjects. The birds were housed in individual cages, in a temperature- and humidity-controlled vivarium, with continuous exposure to water and grit in their home cages. The colony was maintained on a 12-hr light/dark cycle for the duration of the study. The subjects were maintained at 80% of their free-feeding weight throughout the study via postsession feeding as necessary. Sessions were conducted 6 days a week at approximately the same time each day.

### *Apparatus*

The experiment was conducted in an operant-conditioning chamber measuring 30 cm high, 80 cm long, and 30 cm deep. The chamber was sound- and light-attenuating with an exhaust fan to provide ventilation and masking noise. One side wall (the intelligence panel) contained a houselight, three horizontally arrayed response keys (2.5 cm in diameter) and a 6-cm by 6-cm opening for access to a solenoid-operated hopper filled with mixed grain located 10 cm above the floor directly below the center key. The center key was horizontally centered on the intelligence panel 25 cm above the floor. The two side keys were located 8 cm to the left and right of the center key (middle of center key to middle of side key). Each key could be transilluminated with a variety of colors and geometric forms using Industrial Electronics in-line projectors (IEEE Model #ENV-130M). Scheduling of experimental events and data collection were controlled via computer using MED-PC® software (Ver. 4.0, Med Associates, St. Albans, VT).

### *Procedure*

Each pigeon was first trained to eat food from the hopper and then trained by shaping (see Catania, 1998) to peck the center key (illuminated white). After the pigeon pecked the center key reliably when lit, shaping was employed to induce it to peck the right and left key (illuminated white). After the pigeon was pecking all three keys reliably when lit, one of the three keys was illuminated red or green and pecks to the illuminated key resulted in access to grain. Additional shaping was used if necessary, and training trials continued until the pigeon reliably pecked each of the three keys when they were illuminated either red or green.

*Matching-to-sample.* Subjects were next trained on the matching-to-sample (MTS) task using a simultaneous MTS procedure. Specifically, discrete trials began with the illumination of the houselight and the center (sample) key with either a red or green hue. A single peck to the sample key illuminated the two side (comparison) keys with matching and nonmatching hues (i.e., sample and comparison keys were illuminated simultaneously). A single peck to the side key illuminated with the same color as the sample key (i.e., the correct match) turned

off the houselight, the sample key, both comparison keys, and raised the food hopper for 3 s followed by a 10-s intertrial interval (ITI). An ITI was employed because previous research has shown that ITIs improve accuracy of pigeon MTS performance (e.g., Thomas, 1979; White, 1985). A single peck to the nonmatching comparison key (i.e., the incorrect response) turned off all lights in the chamber and initiated a 13-s ITI. The 10-s ITI (plus 3-s hopper access) following a correct match, and 13-s ITI following an incorrect match, ensured equal ITIs between trial onsets following a correct or incorrect match.

A two-color (red [R] and green [G]), two-comparison MTS procedure yields four possible trial configurations (RRG, GRR, RGG, GGR). The computer arranged the presentation of these configurations on each trial in a quasirandom order. Specifically, each of the four configurations was presented before any configuration could be repeated (i.e., random selection without replacement). This procedure guarantees that the maximum number of consecutive identical trials is two, the maximum number of consecutive trials on which the same comparison color is correct is four, and the maximum number of consecutive trials on which the same side key is correct is also four.

The development of position and stimulus biases are common during early MTS training (e.g., Cumming & Berryman, 1961; Mackay, 1991). In an effort to minimize the development of such biases, a correction procedure was programmed in which trial configurations with incorrect matches were repeated until the subject made a correct match. For example, if the pigeon pecked the right key in the presence of an RRG configuration, the 13-s ITI would begin and the RRG configuration would be presented again on the subsequent trial, and would continue to be presented after each ITI until the pigeon pecked the correct (i.e., left) comparison key (see Kangas & Branch, 2008, for empirical validation of this procedure). Each session ended upon completion of 72 correct matches.

Each subject was transferred to a zero-delay MTS procedure after 10 consecutive sessions with 85% or greater accuracy (without correction). In this condition, a single peck to the center key turned off the sample and simultaneously illuminated both side keys. The



consequences for pecking the matching or nonmatching key remained the same as before. After 10 consecutive sessions with 85% or greater accuracy in this condition, each pigeon was transferred to the TDMTS procedure.

*Titration delay matching-to-sample.* The TDMTS procedure was identical to the zero-delay MTS procedure described above with the exception that the delay between sample stimulus offset and comparison stimuli onset was adjusted as a function of the pigeon's accuracy on immediately preceding trials. Specifically, every two consecutive correct matches increased the delay by 1 s, and every incorrect match decreased the delay by 1 s (regardless of trial type). The first condition began at a zero-delay; thereafter, each daily session began with the delay value from the end of the previous session.

Each subject was exposed to an ascending series of sample response requirements (FR 1, 2, 4, 8, 16, and 32) across conditions. For example, in the FR 16 condition, the 16<sup>th</sup> peck on the center key turned off the sample key and initiated the delay interval to comparison onset. After a minimum of 20 sessions under a response requirement, performance was assessed for stability. Conditions ended when the mean delay values from the last 10 sessions were all within  $\pm 25\%$  of the average of the 10-session means. An adjusting stability criterion (Sidman, 1960) was used because more variability in the primary dependent measure (i.e., titrated delay) was expected to occur at higher delay values, thus accommodating greater variability at higher adjusted delays.

Each subject was exposed to the next sample response requirement in the ascending sequence noted above unless the 10-session mean of session-wide mean delay values from the current condition was smaller than the value obtained in the previous condition. Following completion of the parametric analysis, all subjects were exposed to the earlier response requirement of FR1 and 3 of the 4 subjects were also subsequently exposed to FR 8 to ascertain the extent to which titrated delay values would be replicated after a history of exposure to higher response requirements.

#### RESULTS AND DISCUSSION

All 4 subjects learned to eat from the hopper and peck all three keys first illuminated white

and then either red or green within approximately 1 to 3 hr of training. No systematic between-subject differences were noted, but each pigeon took a different amount of time before key pecks were reliably observed.

Figure 1 presents data for three properties of performance under the parametric analysis of sample response requirements under the TDMTS procedure. The left column of panels present the mean titrated delay values from the last 10 sessions of each condition for each subject with error bars indicating the standard deviation. In general, the results show that the titrated delay values increased as a function of increased sample response requirements in a curvilinear (positively accelerated) fashion for all subjects. Furthermore, each subject's data reveal a point where a substantial increase in delay values is observed, although under different sample response requirements for different subjects. For example, Subjects 16 and 660 produced a greater than four-fold increase in adjusted delay values following the transition from FR 1 to the FR 2 condition. Subjects 570 and 659, on the other hand, produced large increases in adjusted delay values following the transition from FR 8 to FR 16.

The horizontal lines represent the mean adjusted delay value from the stable sessions of replicated conditions. The FR 1 condition was replicated for all subjects and the FR 8 condition was replicated for 3 of the 4 subjects (Subject 570 was the exception). These data show that the adjusted delay values from the replications of the FR 1 condition were greater than those produced during the original determination for all 4 subjects. For Subjects 16 and 660 the means from the stable sessions were lower than the mean titrated delay value from the original FR 2 exposure. For Subject 570 the FR 1 replication approximated previously observed levels of the FR 8 condition and for Subject 659 the FR 4 condition. The titrated delay value produced during replication of the FR 8 condition was greater than the value produced during the original exposure for Subject 16 but approximately the same for Subjects 659 and 660. Despite the failure to recapture the particular delay values in several of the replications, the relation between adjusted delay value and sample response requirement was reproduced in each case—an increase in sample response requirements

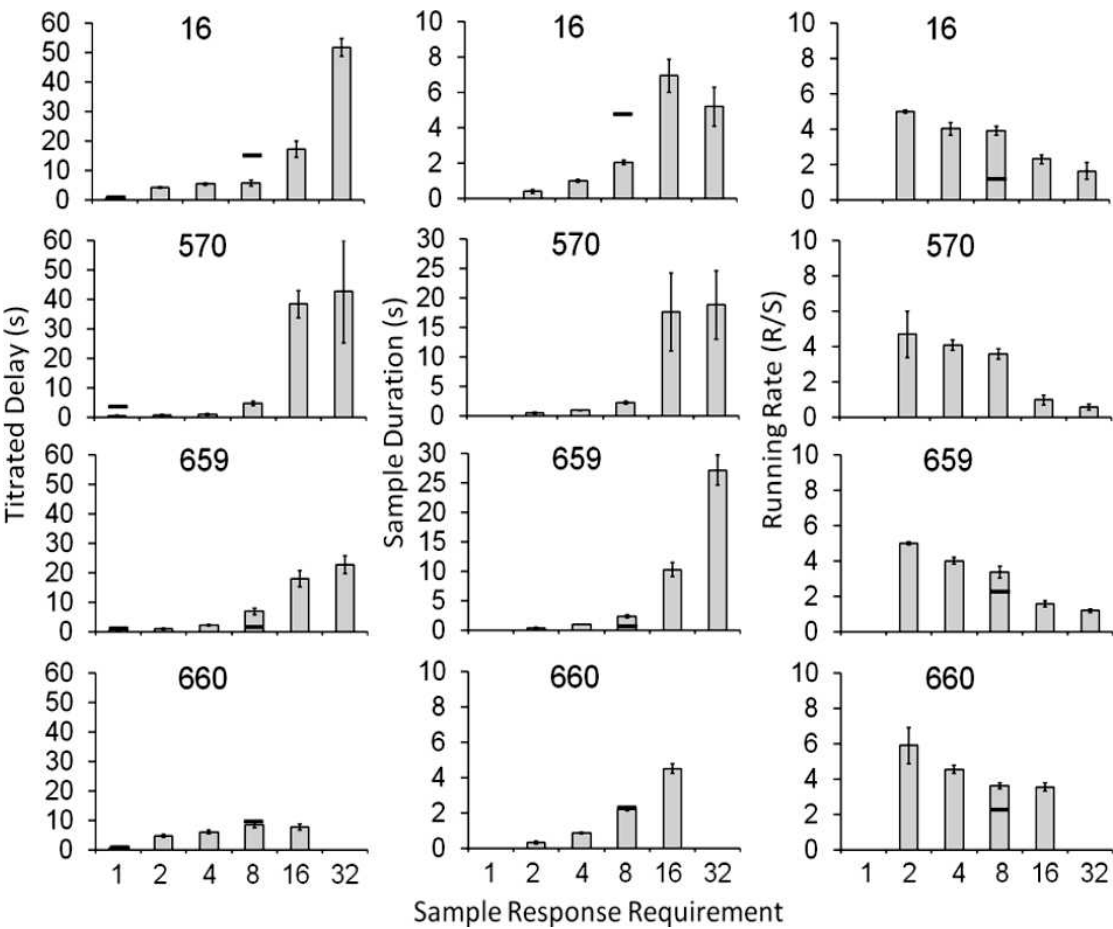


Fig. 1. Data from three properties of performance under the parametric analysis of sample response requirements under the TDMTS procedure. Data are from the last 10 sessions of each condition. Each row shows data from an individual subject. The left column of panels displays the mean titrated delay values for each subject; the middle column of panels shows the means of median time required to complete the response requirement; and the right column of panels depicts means of the median running rate at which the response requirements were completed. Error bars indicate standard deviations.

consistently produced an increase in the mean titrated delay value during the replicated conditions.

The middle column of panels in Figure 1 presents the means of median time required to complete the response requirement (i.e., the time between the first and the last response of the condition's response requirement) during steady-state for each condition (with the exception of the FR 1 condition, for which this analysis was not applicable). These data show that the time required to complete the response requirement increased as the response requirement was increased. This result should not be surprising as larger response

requirements take longer to complete, all else being equal; however, as the data indicate, the increases in durations are proportionately greater across conditions than the increase in FR sample response requirements.

Finally, the right column of panels in Figure 1 presents the means of median running rate (pecks per s from the first to last peck in an FR) at which the response requirements were completed during steady-state for each condition (except FR 1 condition, for which this analysis was not applicable). These data reveal that the rate at which the response requirements were completed systematically decreased across conditions;

that is, all subjects responded more slowly as the response requirements were increased, which is an interesting effect considering even the largest FR values tested were rather small for pigeons as compared to previous research (e.g., Ferster & Skinner, 1957).

Taken together, these data show that all subjects took longer to complete the sample response requirements as the requirements themselves were increased, thus spending proportionally longer in the presence of the sample stimulus than the FR-value increase alone would suggest. Therefore, time spent in the presence of the sample appears to be related to maintaining longer titrated delay values in all subjects. What remains unclear at present, however, is the relative importance of the role of responding on the sample stimulus key and that of simply being in the presence of the sample stimulus. That is, by arranging for the subject to engage in an extended response requirement on the sample stimulus, we can be relatively confident that the subject "sees" the stimulus; the necessity of the responses to the stimulus, however, remains unclear. Future research may be able to tease this relationship apart, for example, by employing procedures similar to those used by Foster, Temple, Mackenzie, DeMello, and Poling (1995) with hens under DMTS procedures and juxtaposing within-subject performance under various sample response requirement conditions with sample stimulus duration conditions, where responses to the sample are prohibited by trial termination. Another strategy could involve programming response-initiated fixed-intervals (RIFI) that match the duration of exposure of a given FR schedule. If fewer responses in the RIFI are made and titrated delay values remain the same or increase, that would lend suggestive evidence that exposure alone may play a large role in the performance.

## EXPERIMENT 2

In Experiment 1, the first trial of the first session under the TDMTS procedure was programmed with a zero delay. In all subsequent sessions, the first trial was programmed with the delay value of the last trial of the previous session. The experiment was programmed that way to identify better the full range of delay values each subject would be able to maintain and how that would change

in relation to extended sample response requirements. Each TDMTS session can, however, be programmed to start with a zero delay, or any other value for that matter. Indeed, several of the studies discussed above programmed daily sessions to begin with a zero delay (e.g., Jarrard & Moise, 1970; Poling et al., 1996; Woodward et al., 1986). Therefore, the purpose of Experiment 2 was two-fold. First, we wanted to determine the reliability of performance when the subject's session began with the same delay value each session, and second, we wanted to determine if, and the extent to which, stable titrated delay values were affected by initial delay values. Would performance approximate a known baseline level under conditions similar to those used in Experiment 1? An affirmative answer would potentially provide evidence of both the experimental reliability and validity of titrated delay as a dependent measure.

## METHOD

### *Subjects*

Four White Carneau pigeons (*Columba livia*), approximately 1 yr old, were obtained from Double-T Farms, Glenwood, Iowa, and were maintained at approximately 85% of their free-feeding weights by postsession feeding as needed (the change of weight across experiments was mandated by the local Institutional Animal Care and Use Committee). The animals were housed in individual cages, in a temperature- and humidity-controlled colony room, with exposure to a 16:8-hr light/dark cycle. Water and grit were available continuously in the birds' home cages. Sessions were conducted 7 days a week at approximately the same time each day.

### *Apparatus*

The experiment was conducted in a sound- and light-attenuating BRS/LVE pigeon chamber with inside dimensions measuring 35 cm high, 30 cm long, and 35 cm deep. One side wall (the intelligence panel) contained a houselight, three horizontally arrayed response keys (2.5 cm in diameter) and a 6-cm by 5-cm opening for access to a solenoid-operated hopper filled with mixed grain. The opening was located 10 cm above the floor and centered below the center key. During each feeder operation, the aperture was illuminat-

ed, and all other lights in the chamber were extinguished. The center key was horizontally centered on the intelligence panel 25 cm above the floor. The two side keys were located 8 cm to the left and right of the center key (middle of center key to middle of side key). Each key could be transilluminated red, green, or white, and a peck with a force of at least 0.15 N counted as a response and was accompanied by a 30-ms feedback tone (2900 Hz) via the operation of a Mallory Sonalert<sup>TM</sup>. To mask extraneous sounds, white noise at approximately 95 dB was present in the room in which sessions were conducted. Scheduling of experimental events and data collection were controlled via a dedicated computer system (Palya & Walter, 1993) operating with a resolution of 1 ms.

### *Procedure*

The 4 subjects in Experiment 2 had a prior history of exposure to the TDMTS task. Specifically, they engaged in a successful systematic replication of Experiment 1 with the difference being exposure to each of the smaller FR response requirement values (1, 2, 4, and 8) for a fixed time-interval stability criterion (Perone, 1991; Sidman, 1960) of 15 sessions per FR value. The terminal FR response requirement of 16 was run to stability and a study examining the effects of cocaine administration was conducted. The present experiment began several weeks after the drug experiment was completed with the subjects engaging in the TDMTS task described below during the intervening time.

Baseline TDMTS performance for Experiment 2 was determined by exposing the subjects to the titrating contingencies exactly as described in Experiment 1 with the exception that the FR16 response requirement remained in effect and each daily session consisted of 48 trials. The baseline condition was conducted for 30 daily sessions. Importantly, as in Experiment 1, during baseline the first trial of each session began with the titrated delay value of the last trial of the previous session.

Following the 30 daily sessions of baseline, each subject's average titrated delay was calculated as the mean titrated delay of the last 10 sessions of baseline. For the experiment proper, each subject was exposed to two conditions—one where the daily start-point

delay value was zero for 30 sessions, and one where the daily start-point value was double the mean titrated delay observed during baseline for 30 sessions. Two subjects (711 and 992) were exposed first to the condition where the daily start-point delay value was zero and 2 subjects (809 and 994) were exposed first to the condition where the daily start-point delay value each day was double the value of their baseline level.

### RESULTS AND DISCUSSION

Each subject's mean titrated delay during baseline is represented by the horizontal reference line in Figure 2. Data paths above and below the mean reference line represent trial-by-trial titrated delay during the 30 sessions of the zero-start-point condition and the 30 sessions of the double-the-mean-start-point condition, respectively. That is, the tick marks on the abscissa indicate the beginning of each session; every data point between the ticks indicates each titrated delay value during each of 48 trials. As the figure indicates, for all 4 subjects in a majority of the sessions, trial-by-trial titrated delay values were adjusted in the direction of levels observed in baseline. Despite the fact that all subjects had sessions with high accuracies adjusting the delay values in the direction of observed baseline values, the near-perfect accuracies needed to achieve baseline levels were usually not observed. Likewise, during the double-the-mean-start-point condition, consistent incorrect responses were observed, driving the delay values down in the direction of values observed in baseline, but intermittent correct responses (which would be predicted even during diminished stimulus control) prevented subjects from reaching baseline levels. Given the repeated clear trends evident in Figure 2, the failure to reach exact baseline levels appears to be related to the number of trials per session. Perhaps with additional trials per session, baseline levels would have been achieved. Finally, although conforming to the patterns observed in the other 3 subjects, Subject 992's higher baseline resulted in a start-point of 56 s that induced very long interresponse times resulting in fewer than 48 trials because of an imposed maximum session length contingency (1.5 hr).

Taken together, the data from both start-point conditions suggest that despite a failure



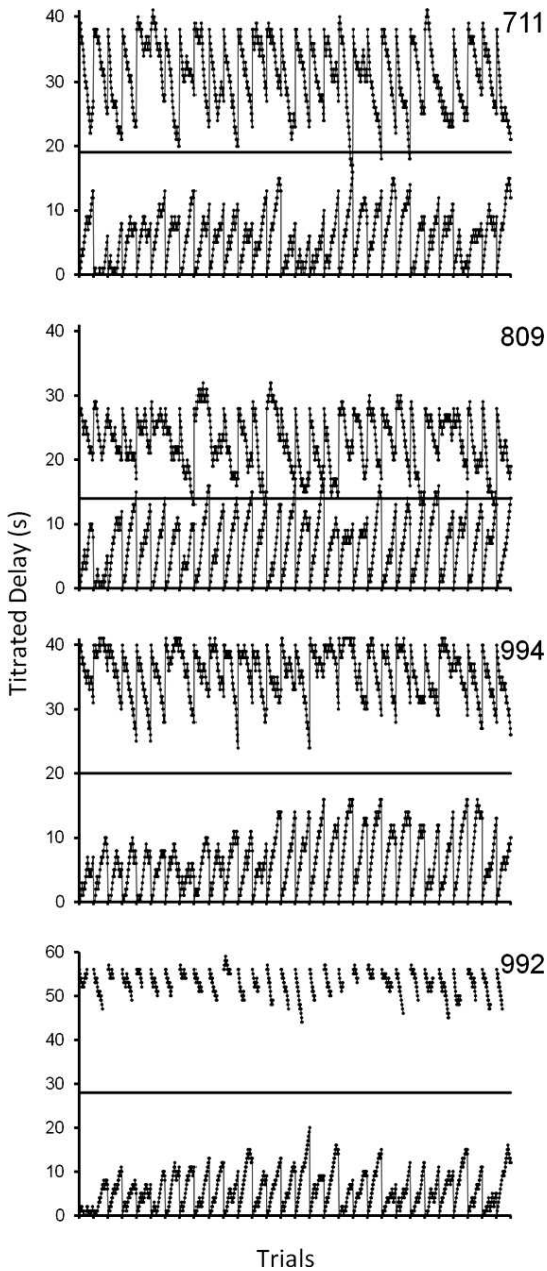


Fig. 2. Titrated delay plotted trial-by-trial in each session in the two experimental conditions. Each graph shows data from an individual subject. Horizontal reference lines in each graph indicate mean titrated delay during baseline. Data paths above and below the reference line represent trial-by-trial titrated delay during the 30 sessions of the zero-start-point condition, and the 30 sessions of double-the-mean-start-point condition, respectively. Tick marks on the abscissa indicate the beginning of each session.

of subjects to achieve reliably the precise delay values observed during baseline, there is a level of delay values that subjects will approach regardless of daily session start-point, all other experimental parameters being equal. Given this outcome, the researcher using the TDMTS task may choose how to arrange the daily session start-point depending on the experimental goals. Starting the session where the previous left off will reveal better the full range of the organism's capability under the programmed conditions. For example, if the researcher is interested in investigating performance-enhancing or -decrementing variables, a stable performance of titrated delay values consistently larger than zero would allow for movement in either direction. Starting each session at the same value will limit the delay values to those obtainable within the set number of programmed discrete trials and step size (cf. Experiment 3), and as these data suggest, if the daily start point is zero, the full capabilities of the organism may never be realized. If the researcher, however, is more interested in how a more circumscribed performance profile in the TDMTS task is affected by some experimental manipulation, and less interested in maximum capabilities, these data suggest that holding the session start-point constant provides a fairly reliable baseline by way of, for example, using daily session-wide accuracies as a primary dependent measure similar to the DMTS task.

### EXPERIMENT 3

In addition to response requirements on the sample key and delay value start point, another contingency parameter programmed in the TDMTS task is step size of delay. This variable, like the two investigated above, has also varied throughout the literature. For example, some have used a 0.5-s step size (e.g., Woodward et al., 1986), 1 s (e.g., Cumming & Berryman, 1965), 2 s (e.g., Ferraro et al., 1971), or a progressive step size (e.g., Scheckel, 1965). One potential advantage of programming a larger step size is the opportunity to observe a larger within-session range of titration; that is, allowing the subject more movement in either direction within-session. The purpose of Experiment 3 was to determine the effects of a larger step size (2-s) than that used in the experiments above on TDMTS performance.

METHOD

*Subjects and Apparatus*

These were the same as in Experiment 2.

*Procedure*

Experiment 3 was conducted immediately after Experiment 2. Baseline for Experiment 3 consisted of a reintroduction of the contingencies where the delay value of the first trial was that of the last trial in the previous session. This was arranged for 30 daily sessions. On the 31<sup>st</sup> session the titrating step size was increased from 1 to 2 s. This parameter remained in effect for 30 daily sessions and was then decreased back to 1 s (return to baseline) for 10 daily sessions.

RESULTS AND DISCUSSION

Figure 3 presents session-wide mean titrated delays with error bars indicating session-wide range during the three conditions of Experiment 3. Vertical dashed lines indicate condition change and horizontal solid lines indicate condition-wide mean titrated delay. As this figure indicates, the condition-wide means did not change systematically across subjects, however, a notable increase in variability in session-to-session mean titrated delay, as well as an increase in the within-session range, were observed during the 2-s step-size condition. That is, upon introduction of the 2-s step size, the variability of daily session mean titrated delay was larger even though the overall condition-wide mean remained about the same, and an increased within-session range of titrated delay (i.e., increased movement during each session) was also observed. In addition, the smaller variability associated with a 1-s step size was successfully replicated when the conditions were reversed.

Figure 4 analyzes the change in within-session range (i.e., the error bars in Figure 3) across the three conditions. Each bar in Figure 4 represents one of the three successive step-size conditions, and the height of the bar indicates the average within-session range during that condition. This effect may initially appear to be simply an artifact of the programmed contingencies; indeed, as Figure 4 indicates, the within-session range approximately doubles as the step size is doubled. It is important to note, however, that the observed performance is not methodologically

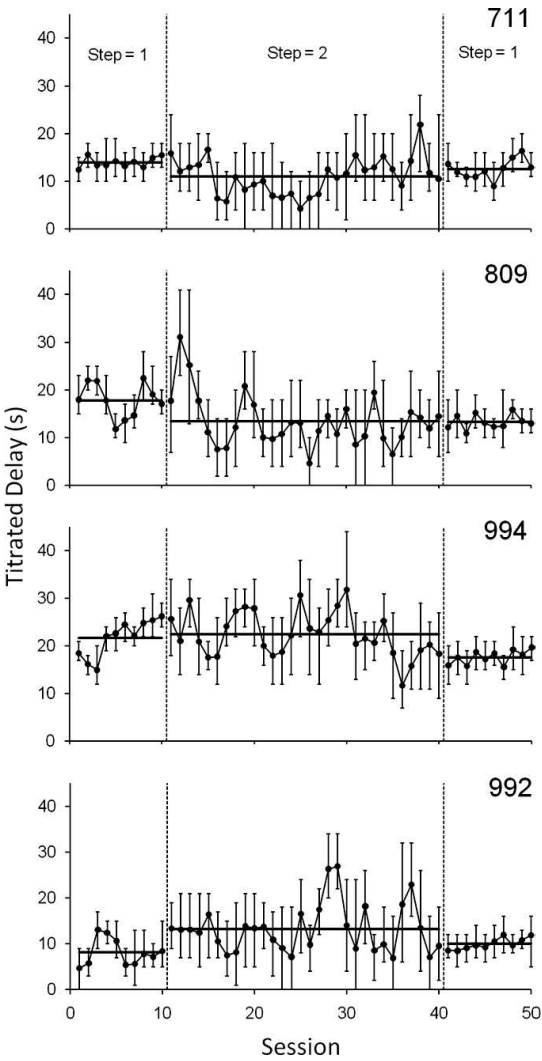


Fig. 3. Session-wide mean titrated delays (error bars indicate session-wide range) plotted over sessions during the three conditions of Experiment 3. Each graph shows data from a single subject. Vertical dashed lines indicate condition change, and horizontal solid lines indicate condition-wide mean titrated delay.

forced by the programmed contingencies. Although the absolute change in titrated delay is doubled under the increased step size, performance approximating the range observed during the 1-s step-size conditions was achievable in the 2-s step-size condition. This would be demonstrated by a hypothetical subject, for example, maintaining a 15-s titrated delay by getting one trial wrong, dropping to 13 s, getting the next two correct, increasing to 15 s, and so on. That hypothet-

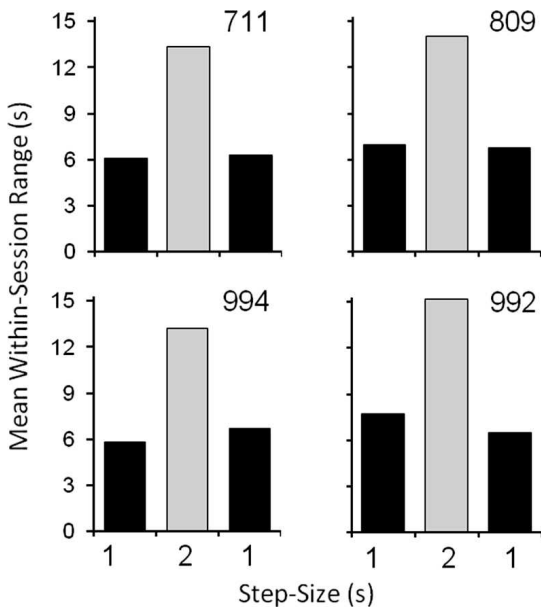


Fig. 4. Means of within-session ranges (i.e., the vertical extent of the error bars in Figure 3) across the three conditions of Experiment 3. Each bar represents one of the three step-size conditions; height of the bar indicates the average number of seconds of within-session range during that condition (i.e., mean difference of each session's highest delay value and the lowest delay value).

ical example results in a 2-s range where as all 4 subjects maintained approximately a 6-s range under the smaller step size allowing our hypothetical subject three times more variability under the 2-s step size to successfully approximate values observed under the 1-s step size. It is possible, however, that the relationship between step size and session-to-session variability may nonetheless maintain a close correlation. Additional research including a wider parametric analysis is needed, however, to provide more detail of this effect. For example, would a 3-s step size maintain approximately the same average titrated delay level but triple the variability relative to 1 s?

Regardless, all 4 subjects maintained a relatively consistent overall mean titrated delay value when the step size was 1-s and within-session variability was less than that seen when the 2-s step-size condition was in effect. This suggests that having a step size greater than 1 s may introduce unnecessary variability in TDMTS performance. Moreover, as Figure 3 shows, 3 of the 4 subjects have titrated delay values that at least momentarily reach the floor

(i.e., 0 s) during the 2-s step-size condition—something that was almost never observed with an FR16 sample requirement and a 1-s step size.

There may be circumstances, however, when a step size greater than 1 s may prove useful. For example, if a researcher is interested in allowing for a larger possible range in titrated delay under a limited number of discrete trials per session, a larger step size will achieve that objective—more room to move within-session may be worth increased variability in session-wide mean titrated delays and within-session range depending on the experimental question.

## GENERAL DISCUSSION

The present series of experiments was designed to increase our understanding of environmental influences on performance in the TDMTS procedure by examining the effects of several specific procedural variables. The purpose was not to prescribe a rigid standard methodological practice when employing the TDMTS procedure but to identify functions of the programmed parameters. For example, Experiment 1 assessed a method to increase the time the subject spends in the presence of the sample stimulus by programming extended response requirements. That resulted in titrated delay values well above the minimum possible (i.e., 0-s delay), a circumstance that may be useful if it is important to evaluate effects of a given independent variable (e.g., pharmacological agent) on titrated delay that can change in either direction. Results from Experiment 2 highlight the tradeoff between allowing for potentially greater range of across-session movement of titrated delay values by programming each session to start with the delay value with which the previous session ended, at the expense of producing less variable within-session performance that can be captured by simple accuracy when using the same start-point delay value each session. Results from Experiment 3 highlight the tradeoff between allowing for potentially greater within-session movement of titrated delay values at the expense of increased within- and across-session variability associated with larger step sizes.

Although the present research was focused on three components of the TDMTS proce-

ture, several others remain unexamined and would serve as important areas of future research. For example, in the present series of experiments, two consecutive correct responses were required to increase the delay and one incorrect response decreased the delay. These contingencies were designed to maintain accuracy at approximately 67% correct during steady-state performance. These contingencies could vary, for example, requiring three correct to increase the delay and one incorrect to decrease maintaining accuracy at approximately 75% correct during steady-state performance. One might predict that those contingencies would result in lower titrated delay values relative to the contingencies programmed in the present experiments but that is, of course, an empirical question. Other potential endeavors include investigations of the role of response requirements on the comparison stimuli, length of ITI, varying reinforcer magnitude, and species comparisons, among others.

To conclude, the TDMTS procedure appears to be a promising counterpart to the DMTS task for examining the features of delayed stimulus control (i.e., remembering/memory). It is unlikely that one experimental preparation will capture all features of the complex phenomena involved in action at a temporal distance, but additional tools at the disposal of the memory researcher should help our understanding of these important behavioral processes.

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